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The voltammetric study of 2-mercapto-5-phenylammino-1,3,4-thiadiazole using carbon paste electrodes[1]

Robert Săndulescu [a,*], Iuliu Marian [b], Simona Mirel [a], Radu Oprean [a], Liviu Roman

[a] *Department of Analytical Chemistry, Faculty of Pharmacy, University of Medicine and Pharmacy 'Iuliu Haţieganu', Pasteur St., no. 4, 3400 Cluj-Napoca, Romania*

[b] *Department of Physical Chemistry, Faculty of Chemistry, 'Babeş-Bolyai' University, Arany Janos St., no. 11, 3400 Cluj-Napoca, Romania*

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Abstract

A rapid and accurate voltammetric method for the quantitative determination of 2-mercapto-5-phenylammino-1,3,4-thiadiazole (MPATD) with carbon paste electrodes (CPE) has been developed. The study was made by cyclic voltammetry between -0.4 and $+0.6$ V with 50 mV s^{-1} sweep rate in aqueous solution. After successive oxidation/reduction cycles we found a total oxidation of MPATD at $+0.45$ V. As the compound is oxidated, the reduction current peak increases at $+0.13$ V, indicating an irreversible process. Following only the oxidation process in the -0.1 to $+0.6$ V range, we investigated the optimum scan rates at different current densities and pH values (realised with buffers, pH between 1.0 and 10.0) with CPE versus Ag/AgCl reference electrode using linear sweep voltammetry. We found a good linear relation between the current peak height and concentration in a $2.5 \cdot 10^{-9}$–$1.25 \cdot 10^{-7}$ mol ml^{-1}. This method allows the quantitative detection of the MPATD as it or from dosage forms and biological media.

Keywords: Mercapto-1,3,4-thiadiazoles; Carbon paste electrodes; Cyclic voltammetry; Linear sweep voltammetry

1. Introduction

The electrochemical and electroanalytical methods are presently reconsidered, due to the intense fundamental and applicative research. The most used methods are the ones based on redox processes (cycles) The redox reactions investigated this way can provide information regarding concentration, kinetics, reaction mechanisms, chemical status and other parameters of the chemical species in solutions. By electrochemical techniques we can study phenomena's from the neurotransmitter behaviour in biological media, to brighter concentrations in plating baths, to initiator behaviour in polymerisation to the speciation of heavy metal ions in natural waters [1,2].

* Corresponding author. Fax: +40 64 197256; e-mail: rsandulescu@usa.net

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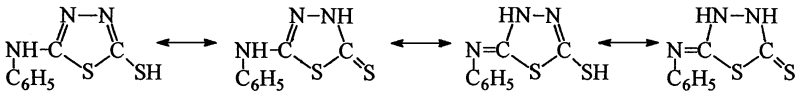
The electroanalytical techniques used in our work are the cyclic voltammetry and the linear sweep voltammetry, using a CPE as working electrode. Presently all types of carbon paste electrodes (CPEs) are widely used in the electroanalysis field (including drug or pollutants analysis or the analysis of some biologically-active molecules). Their study is still of great interest fact which explains the great number of papers published [3–5].



The CPEs offer a lot of advantages for the electrochemical study of inorganic and organic compounds, they are cheap, easy to prepare and to use. Their electroanalytical performances are very good, different from those of other solid electrodes: low noise or background current in a wide range of potentials, low risk of irreversible degradation of the surface, they allow the easy modification through several techniques and preconcentration through adsorption–extraction.

However, the CPEs have disadvantages too, such as instability in hydro-organic solvents and hydrodynamic conditions, the variability of paste composition, sometimes the slow electron-transfer kinetics and manual renewing of the surface. All those can give random errors.

Continuing the tradition of the study of some organic compounds containing S and N, started more than 40 years ago by A. Silberg et al. [6] that synthesised a new heterocycle class, the 2-mercapto-5*R*-ammino-1,3,4-thiadiazole derivatives by cyclisation of disubstituted dithiourea, we chose 2-mercapto-5-phenylammino-1,3,4-thiadiazole (MPATD) for our study. We considered, in this choice, its applications in analysis and its biological features (bacteriostatic, inhibitor of plant growth processes).

Studies made through the last four decades regarding the MPATD complexes and their reactions with most polarising and polarisable cations, have revealed its analytical properties. The results of these studies were put in a lot of gravimetric (Pb^{2+}, Cu^{2+}, Hg^{2+}, Ag^{+}, Tl^{+}) [7,8], photometric (Bi^{3+}, Ni^{2+}, Pd^{2+}) [7,9], potentiometric, conductimetric (Ag^{+}, Pb^{2+}, Hg^{2+}, Cd^{2+}) [8,10,11] and enthalpymetric dosage methods [12].

The analytical interest for MPATD is due to the acidic–basic ($K_a = 3.34.10^{-6}$; $pK_a = 5.48$) and redox properties as MPATD has more tautomer forms.

The tiolic form cannot exist otherwise than solved, as the tautomeric tion–tiolic balance is more shifted towards the tiolic form, as the polarity of the solvent and the pH increases.

The last reason for using this compound is its resemblance to a range of biologically-active molecules (enzymes, proteins) that contain tiolic groups, molecules that are implicated in cellar or tissular redox-reactions. In this case, MPATD and other thiadiazoles can be used as models to establish some relations between the electrochemical properties and the pharmacological ones, or the biological action or behaviour of some drugs or chemical species with biochemical significance.

2. Experimental

2.1. Apparatus

A PS 4 potentiostat (Meinsberg, Germany), a PV 2 variator (Meinsberg, Germany), a Digital Multimeter E 0302 (IEMI, Romania) and an Iféléc 2025 recorder (France) were used for the cyclic voltammetry studies, and a Bruker E 100 potentiostat and a XY Hewlett–Packard 7035 B recorder were used for the linear sweep voltammetry. The measurements were performed with use of a polarographic cell containing the working electrode (CPE), Ag/AgCl as reference electrode and a platinum wire as the auxiliary electrode.

Samples were measured with 10, 100 and 500 μl Hamilton syringes.

The pH of solutions was determined with a Chemcadet 5986-62 pH meter (Cole Parmer) using a combined glass electrode.

All experiments were carried out at room temperature (22°C). The cyclic voltammograms were recorded in argon-deaerated solutions.

2.2. Reagents

All chemicals were of analytical grade (Merck or Reactivul Bucureşti) and were used as received. Glycocole and citric acid were of pharmaceutical grade (F.R.X, Romanian Pharmacopoeia Xth edn.).

2-Mercapto-5-phenylammino-1,3,4-thiadiazole was prepared 'ex tempore', crystallised and purified (m.p. 215–216°C) in the Organic Chemistry lab using analytical grade (Merck) ingredients. The identity of the compound was confirmed by elemental analysis, IR and NMR spectroscopy. The stock solutions and buffer solutions were prepared using deionized water as follows.

2.2.1. 10^{-2} M MPATD solution

2-Mercapto-5-phenylammino-1,3,4-thiadiazole (0.050 g) was weighed into a 25 ml calibrated volumetric flask, dissolved in ethyl alcohol and diluted to the sign. The volumetric flask was kept in darkness, to avoid photoxydation.

2.2.2. 10^{-1} M glycocole solution

Glycocole (7.505 g) and NaCl (5.850 g) were weighed into a 1 l calibrated volumetric flask, dissolved in deionized water and diluted to 1000 ml with deionized water.

2.2.3. Citric acid solution

Citric acid (21.002 g) was weighed into a 1 l calibrated volumetric flask, dissolved in deionized water and diluted to 1000 ml with deionized water.

2.2.4. Disodium hydrogen phosphate solution

$Na_2HPO_4 \times 2H_2O$ (35.620 g) was weighed into a 1 l calibrated volumetric flask, dissolved in deionized water and diluted to 1000 ml with deionized water.

The buffer solutions were prepared by mixing into 100 ml calibrated volumetric flasks of different volumes of citric acid and disodium hydrogen solution (for pH 4.0–6.0 and 8.0), and glycocole solution the pH being adjusted to the desired value by HCl (pH 1.0–3.0) or NaOH (pH 9.0 and 10.0). For the pH 7.0 we used a Radelkis (Hungary) buffer solution.

The CPE was prepared by using commercial carbon paste from Metrohm (code 6280.1000) witch was packed into the Teflon body of the electrode (1 mm i.d.). Before the measurements the electrode surface was smoothed to a mirror finish using a clean paper card.

3. Results and discussions

3.1. Cyclic voltammetry

The determinations made by cyclic voltammetry within the potential range: -1 to $+1$ V have revealed the presence of two oxidation steps: the first one at $+0.45$ V and the second at $+0.96$ V (Fig. 1).

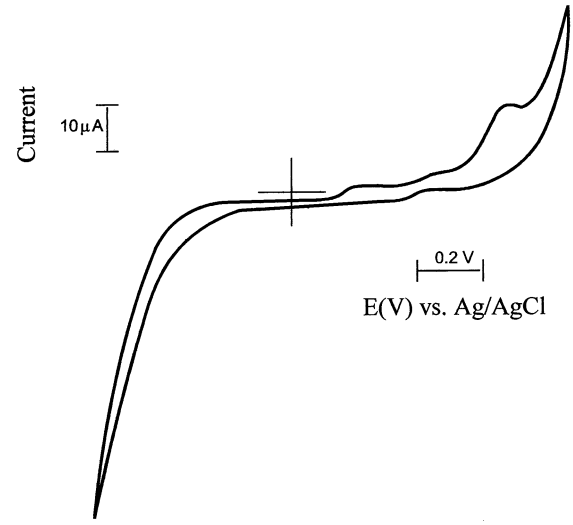


Fig. 1. Cyclic voltammogram of MPATD (10 μl 10^{-2} M alcoholic solution in 5 ml argon deaerated deionized water, CPE versus Ag/AgCl (Pt), potential range -1.0 to $+1.0$ V, scan rate 10 mV s^{-1}, current scale 50 μA).

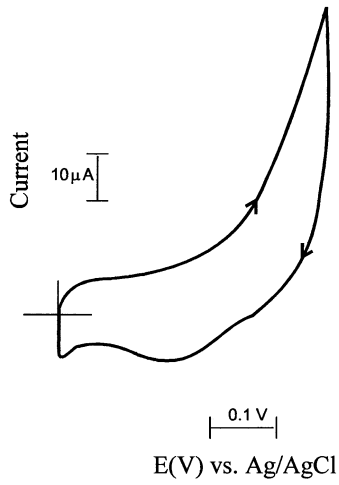


Fig. 2. Cyclic voltammogram of MPATD (24th successive scan, 10 μl 10^{-2} M alcoholic solution in 5 ml argon deaerated deionized water, CPE versus Ag/AgCl (Pt), potential range -0.4 to $+0.6$ V, scan rate 10 mV s^{-1}, current scale 500 nA).

At repeated cycles there is a drift of the two steps towards more positive potentials, with a pronounced aplatisation of the first step. The process is irreversible. The oxidation mechanisms are still to be studied, but one thing is clear: after the complete passing of the compound in the first oxidated form, that reduces its self at 0.13 V (Fig. 2).

Analytically speaking, the first oxidated form is of great interest. If we use only one oxidation sweep, there is no drift in the peak potential on the new electrode surface.

3.2. Linear sweep voltammetry

The study of the electroanalytical behaviour of MPATD has been remade with linear sweep voltammetry, using as a working electrode the CPE, as a reference electrode Ag/AgCl and a platinum wire as an auxiliary electrode.

The drawing of the intensity/potential curve between -0.1 and 1.3 V confirmed the presence of the two oxidation steps (Fig. 3). The main oxidation reaction is probably the one in which the disulfide is formed.

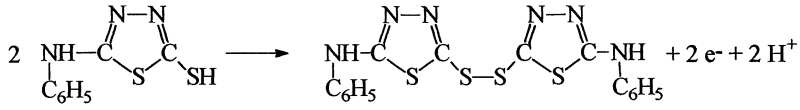
To be able to establish the optimum working conditions we have diminished the potential range even more, from -0.1 to 0.65 V; the new domain contains only the first and the most stable-as reproducibility-step. 5 μl 10^{-2} M alcoholic solution was used to do several registrations, at different sensibilities and sweep speeds for the studied potential, intensity and concentration domains; have been established: 500 nA or 1 μA and 50 mV s^{-1}.

If the buffer solutions with the pH between 1.0 and 10.0 were used, between -0.1 and 0.9 V, a drift of the oxidation potential from 0.7 to 0.25 V was observed, with a relatively constant zone between pH 4.0–7.0, where the E_{peak} is independent of the pH (Fig. 4).

Preliminary studies have shown that until a pH = 3.0 is reached, there is only one oxidation peak, in the 0.7 and 0.65 V area. At pHs greater than 3.0 a second oxidation peak in the 0.55–0.65 range can be observed (Fig. 5). If the potential domains is not increased to the 0.9 V value or more, we can see that for the pH values between 4.0 and 8.0, only the first oxidation step is situated between 0.48 and 0.42 V.

To obtain a good reproducibility of the determination the etching was necessary. This was done by extracting the electrode from the cell and its polishing on a surface with a low roughness degree (paper card). The experiments are made only after a time interval after the immersion of the electrode in the solution. The best time is 5 min in the stationary regime. After each experiment the stirring for ~ 2 min was necessary, to re-establish the double electric layer on the electrode surface. Under these conditions (with the surface remade) the oxidation potentials are the same, the height of the peaks varying very little probably because of the physisorption phenomena.

At acid and respectively neutral pHs (1.0–7.0) the experiments have proved a good reproducibility, so that the etching was no further necessary.



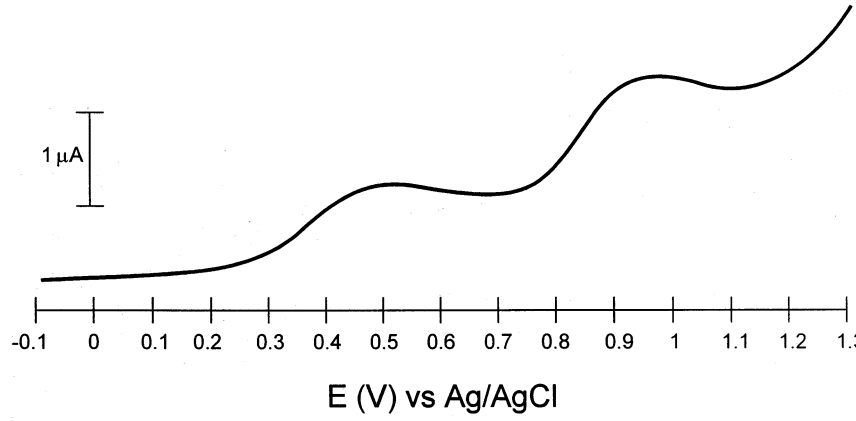


Fig. 3. Linear sweep voltammogram of MPATD (5 μl 10^{-2} M alcoholic solution in 4 ml deionized water, scan rate 50 mV s^{-1}).

For alkaline pHs (8.0–10.0) the etching of the surface is compulsory, because the next curves cannot be registered, due to the fast loss of the sensibility of the electrode. The reasons of these phenomena could be the degradation of the electrode surface (through dissolution, emulsion or corrosion) in alkaline media or the chemosorption of the oxidated species, the response of the surface being totally different. In this case, the following results are drifted to higher potentials and lower intensity, until the complete aplatisation.

To determine the calibration graph the oxidation curves were drawn by linear sweep voltammetry using a CPE with the surface smoothed, in an electrochemical cell together with the reference electrode (Ag/AgCl) and the auxiliary electrode (a platinum wire). The cell also contains 4 ml of buffer solution with the pH 4.0 or 5.0, exactly measured with a pipette. The electrodes are left into the buffer solution for 10–15 min and the solution is stirred up for 2 min before each experiment, after verifying the baseline. To this solution we successively added, with a Hamilton syringe, samples between 1 and 15 μl 10^{-2} M alcoholic solution of MPATD, stirring up before each replicate. Each determination has been repeated three times stirring the solution for 2 min before each replicate. The results, give in mm or μA have been statistically interpreted by the least squares method.

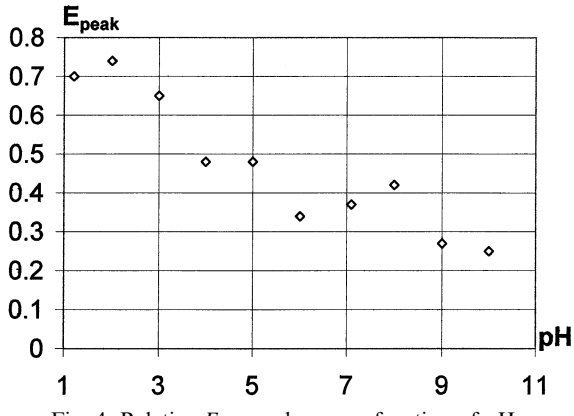


Fig. 4. Relative E_{peak}, values as a function of pH.

In anodic polarisation with buffer solutions of a pH = 4.0–5.0, the oxidation peak occur in the potential domain between + 0.40 and 0.45 V, in respect with the MPATD concentration. No big deviation of the peak has been observed, the differences being of a 10 mV range.

A calibration curve was calculated for the range $2.5 \cdot 10^{-9}$–$1.25 \cdot 10^{-7}$ mol ml^{-1}; $Y = (5.860 \pm 0.08)x + (5.311 \pm 0.68)$, where Y is in nA and x is in μmoles; $r = 0.9982$.

The calculated repeatability for several samples ($n = 41$) corresponded to a relative standard deviation of 2.24%. The reproducibility was calculated from three series of 12 samples with different concentrations, 2.5–50 nmol ml^{-1} measured 3 consecutive days, using each time new electrode

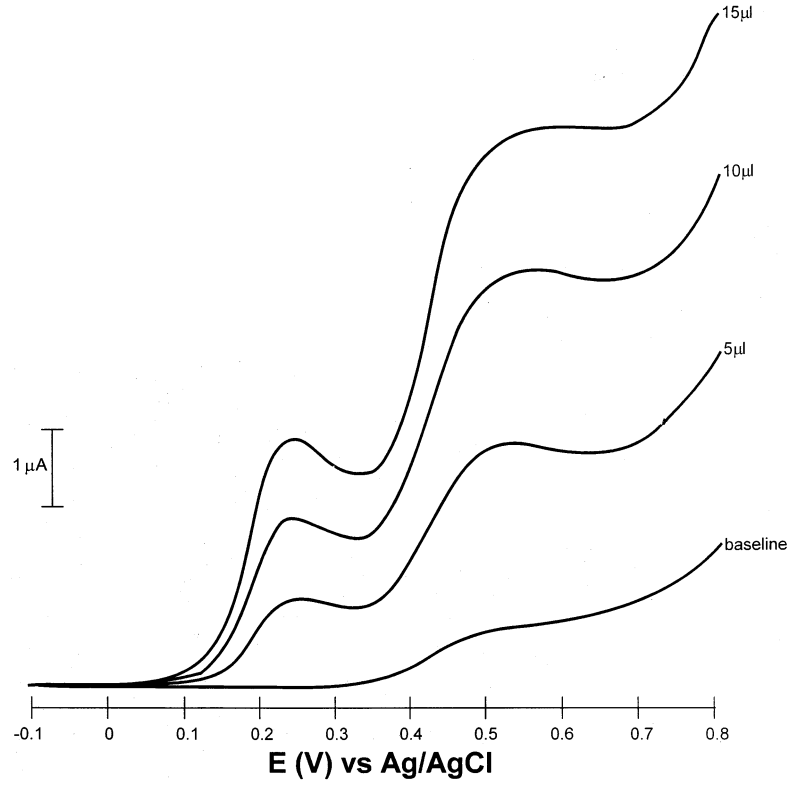


Fig. 5. LS voltammograms of MPATD in buffer solution (pH 10.0, scan rate 50 mV s^{-1}, 500 nA).

surface, and was found to be 2.35%. The accuracy and fidelity of the results decreases significantly in the 1–5 µl range (2.5–12.5 nmol ml^{-1}), perhaps because the detection limit is in that region.

4. Conclusions

The electrochemical behaviour of 2-mercapto-5-phenylammino-1,3,4-thiadiazole (MPATD) was studied by cyclic and linear sweep voltammetry using carbon paste electrode as working electrode vs. Ag/AgCl as reference electrode and Pt as auxiliary electrode. After successive oxidation/reduction cycles between -0.4 and $+0.6$ V, with 50 mV s^{-1} sweep rate we found a total oxidation of MPATD at $+0.40$ and $+0.45$ V. The process is irreversible. Investigating only the first oxidation step by linear sweep voltammetry in the -0.1 to $+0.6$ V range using different current densities, scan rates and pH values we developed a rapid, accurate and reproducible method for the quantitative determination of MPATD. The CPE response was linear in respect with MPATD concentration range between $2.5 \cdot 10^{-9}$ and $1.25 \cdot 10^{-7}$ mol ml^{-1} ($r = 0.998$), allowing its quantitative detection from dosage forms or biological media.

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